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ABSTRACT

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Nr. 6

DOES COMPUTER-ASSISTED INSTRUCTION REDUCE INDIVIDUAL DIFFERENCES?

August Flammer

1976

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ZUSAMMENFASSUNG: Vermindert computerunterstützter Unterricht Individuelle Differenzen?[1)]

Die meisten bekannten Korrelationsmatrizen von mehrfach wiederholten Messungen weisen eine Quasi-Simplex-Form (Guttman) auf. Diese Form ist verträglich mit der Annahme, dass zwischen den Messungen liegende Veränderungen (Lern- oder Entwicklungseffekte) additiv und mit den vorausgehenden Messungen nicht korreliert sind, die Korrelationen zwischen den Messungen also nur durch sog. Ueberlappungen bedingt sind.

Zur Prüfung dieser Erklärung wurden an Volksschülern im Fach Mathematik Lernzeitmessungen für sukzessive curriculare Einheiten durchgeführt unter Bedingungen, die keine Ueberlappung zuliessen (je identische operationalisierte Niveau-Kriterien). Die Ergebnisse liessen weder einen auch der Ueberlappungshypothese zu erwartenden Ausfall oder auch nur Abbau der Lernzeitinterkorrelationen erkennen noch auch eine sukzessive Verminderung der interindividuellen Varianz überhaupt, wie Bloom vorhergesagt hatte.

RESUME: Y a-t-il diminution des différences individuelles dans l'enseignement assisté par ordinateur?

La presque totalité des matrices de corrélations entre les reprises successives de tests est characterisée par la forme d'un 'quasi-simplex' (Guttman). Cette forme peut être la conséquence du fait que les changements interindividuels entre deux mesures (effets d'apprentissage ou de développement quelconque) soient en même temps additifs et non-corrélés avec les mesures précédentes. Cela voudrait dire que les corrélations entre les mesures dans les matrices mentionnées ne soient rien que la conséquence d'un 'overlap' de la variation antérieure (Anderson).

Pour tester cette hypothèse les temps individuels ont été relevés qui étaient nécessaires pour apprendre des éléments successifs d'un curriculum hiérarchique de mathématique à l'école primaire, et cela sous des conditions qui permettaient à écarter tout overlap.

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1) Für eine detaillierte deutschsprachige Darstellung von Hauptteilen dieser Arbeit wird auf die Zeitschrift für Experimentelle und Angewandte Psychologie (1973, 20, 529-546) verwiesen.

Les corrélations obtenues entre ces mesures successives étaient positives et ne montraient aucune tendance à se diminuer de même que les variances interindividuelles restaient stables même après une année d'expérience avec la nouvelle stratégie d'apprentissage (mastery-learning strategy). Ces résultats sont interprétés comme invalidant nettement l'hypothèse de l'overlap comme explication du quasi-simplex ainsi que certaines prédictions pédagogiques concernant les différences interindividuelles sous le régime de l'enseignement assisté par ordinateur (Bloom).

ABSTRACT

The interrelationship of Computer Assisted Instruction and individual differences has been investigated. Two hypotheses were tested: (a) Bloom's hypothesis of decreasing individual differences under a Mastery-Learning Strategy and (b) the random walk interpretation of simplicial correlation matrices. Stanford's Computer-Assisted Instruction (CAI) Math Program was run with 723 first to sixth graders in three States. Neither of the two hypotheses was supported by the data. For the first hypothesis a compensation effect of slow and fast learner variance components as well as an ATI interpretation are discussed. The second hypothesis has been restated as a restricted random walk hypothesis.

Does Computer-Assisted Instruction Reduce Individual Differences?[1)]

The steady decrease of correlation coefficients between performance measures as the time interval between these measures increases is a well established empirical finding (Honzik, 1938; Bayley, 1949; Fleishman, 1953; Bilodeau, 1965; Gendre, 1971; to cite just a few pertinent references).

Honzik (1938) was the first to account for this finding by pointing out that the correlation coefficients of two intelligence measures corresponded roughly to the chronological age (CA) quotient, i.e. CA at first measure divided by CA on a later occasion. Anderson (1939) suggested to replace CA by mental age (MA) and to square the correlation coefficient (r) thus making it consistent with the hypothesis that the covariation simply represents the carryover or overlap of the reliable ID variance from the first measure to the second measure and that any gained variance is uncorrelated to the previous measure. He considered the determination coefficient (r^2) as a linear function of the MA quotient. Thus, the Overlap Hypothesis implies a growth to be additive and individual gains in intelligence measures to be uncorrelated with individual differences (ID's) on a previous level.

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1) This experiment has been made possible by Grant SG-86 of the Swiss National Fund for Scientific Research and by the provision of facilities by the Institute for Mathematical Studies in the Social Sciences at Stanford University. Grateful acknowledgement is given for valuable help in getting into the Stanford CAI system provided by Patrick Suppes, Mike R. Rauch, Rainer W. Schulz, Barbara W. Searle and Paul V. Lorton, Jr. The author is also indebted to Carol Fanicucci, University of Wisconsin in Madison, and Margret Rihs, University of Fribourg, for critical reading of earlier versions. - A great part of the results reported herein have been published in German in the Zeitschrift für experimentelle und angewandte Psychologie 1973, 20, 529-546.

In the domain of ID's in learning essentially the same hypothesis has been put forward, but in a formally more rigorous form. If two items of different difficulties lie on a common Guttman scale, all subjects mastering the more difficult item (I_2) are expected to show mastery of the easier one (I_1). However, there is no way to predict on the basis of the data in I_1 which subjects that mastered I_1 will fail in I_2. Take a number of items all lying on the same Guttman scale, arranged in order of increasing difficulty, then the intercorrelation matrix will contain correlation coefficients decreasing steadily along rows and columns with increasing distance from the main diagonale. Such a set of variables is called a simplex.

The discovery of the similarity between such simplex correlation matrices and most of the learning trial correlation matrices (Humphreys, 1960; Jones, 1962; 1969) has independently led to efforts attempting to explain the role of ID's in learning (Jones, 1962; 1969; Corballis, 1965; Alvord, 1969; Cardinet and Querton, 1970). It was suggested that the simplex-like structure implies that the ID's of the gain from one item to another is unrelated to the ID's of the first item, because of the gain being additive and random. For our purposes the Overlap and the Simplex Hypothesis are equivalent. Both turn out to be difficult to test. Let us demonstrate this with the Overlap Hypothesis in the domain of intellectual growth.

Even if the Overlap formula fits empirical correlation matrices, one would hesitate to adopt the implications of additive growth and unrelatedness of gains. To take an example, some of the variance in the first measure could get lost, but in terms of covariation with the second measure there could be a certain amount of covariation with gains just enough to compensate for lost (co-)variation.

There are domains where the additivity assumption seems reasonable a priori, e.g., physical growth. Insofar as correlation matrices of physical growth measures correspond to the Overlap formula, one might be led to the interpretation that gain is not correlated. Incidentally, one would be surprised by such a finding, because ID's in physical growth seemed, until now, to be bound very much to heredity factors. Suppose, data support the Overlap Hypothesis for physical growth, why not accept it also for mental growth measures? The reason is, that mental growth is hardly

more bound to heredity that physical growth.

This was roughly one line of argumentation adopted by Bloom (1964). It not only allowed the interpretation that ID's in mental growth are not bound to previous measures and not even to heredity, but it also enabled Bloom to establish a sort of a rational scale of mental development, for the Overlap Hypothesis implies such a scale. To establish such a scale is very important for the educator if at the same time it is true, that gains are not influenced by genetic endowment but probably exclusively a product of education and that all what creates lasting ID's is education.

Yet, this author questions the validity of Bloom's argumentation. Argueing solely on the basis of Blooms charts for body height and physical strength, the additivity assumption might seem reasonable, but it is rather striking to find in these very charts much lower correlations than predicted during early adolescence and higher than predicted correlations on other age levels. Occasionally the gain correlations are even negative during early adolescence. A most obvious explanation would be the well known finding of a rhythmical course of growth development. Needless to say that there are individual differences in such growth rhythms in terms of individual points in time. Thus, as far as there are growth rhythms and ID's in these rhythms, possible predictability tends to be underestimated by the linear correlation.

This critique does not falsify the Overlap Hypothesis for mental growth and learning. It only rejects the verification attempt via physical growth. What would be a better way to test the hypothesis for mental growth? The crucial problem is that of a rational scale one would need in order to test and not as a result of the hypothesis validation.

Maybe it is unfair to require quasi-absolute fitting for a new hypothesis which apparently bears tremendous and very desirable implications. Even if some bit of variance of gain ID's remains correlated, the major part is eventually not. It was on this ground that Bloom (1971 a, 1971 b, 1972) stepped further in educational programmes. He proposed the Mastery-Learning Strategy (MLS), based on Carroll's Model of School Learning (1962, 1963 a). Bloom argued, that mastery of prerequisite knowledge or skill units

is indispensable for a successfull future learning experience. He proposed to use frequent evaluations and remedial instruction in order to guarantee that all learners do have the same prerequisites. In this way he suggested the ID's to be reduced successively, for the reason that overlap was reduced through previous equal mastery of all individuals. He did not expect this elimination to be sudden and complete. However, he appears to have found evidence for a slow decrease of ID's not only with regard to final performance (wich would be trivial, since the strategy was designed to produce precisely this effect) but also in regard to learning time and amount of remedial instruction required; "... we never did reach the vanishing point, although we have observed situations in which the variation in time and help required on the later units was only ten percent of the variation observed in the first learning task (or unit) in the sequential series" (Bloom, 1971 b, p. 8; see also 1973 a, p.7, 1973 b, p.22). Unfortunately, exact reports on there experiments are not available to us.

The present study attempts to investigate this aspect by focussing on the development of variances and correlations of learning outcomes in subsequent learning units while applying the Mastery-Learning Strategy. Some earlier studies of the role of ID's in a Mastery-Learning Strategy type of instruction do provide some piecemeal information, but does not support Bloom's contention.

Carroll (1963 b, 1963 c) taught Mandarin Chinese to 15 adults using a teaching machine. One of his progress charts (1963 b, p. 38) shows loosely correlated learning times per subsequent learning units and an increase in the ID variance especially in early units. However he did not quite apply what would now be called a Mastery-Learning Strategy; his students received criterion level recommendations for each unit but were told they could decide when to go on to the next unit.-In the Individual Prescribed Instruction Project,Glaser (1968) found correlations of .37 an .45 between the number of elementary school mathematics units mastered in subsequent years. There was also some increase in spread with respect to the number of units mastered. Nevertheless,Glaser was doubtful whether the unit scale was comparable over the years, since the average number of units mastered increased, too.

Atkinson (1968) obtained more conclusive information when in a Computer-Assisted Instruction (CAI) sample he compared the fastest reading students with the medium and the slowest ones. The order of learning rate remained unchanged over a half-year period. Assuming that these students were caracteristic for the population, high intercorrelations between increments and an increase of the variance should be expected.

On the basis of this evidence a more thorough investigation of the role of individual differences in subsequent learning trials seems warranted. The objective of this study is to decide whether a Mastery-Learning Strategy results in a gradual reduction of individual differences, variance, and covariance in subsequent learning trials. Using individually needed learning times to acquire subsequent mastery of a hierarchy of learning goals, the study was able to sidestep both the problem of the rational scale of performance measures and the problem of ID's in rhythms.

METHOD

The learning program

The Mastery-Learning Strategy adopted for this experiment consisted of a well sequenced computer-assisted instruction program (CAI) in which provisions were made to insure that each student could only progress when he had reached a predetermined performance level in the preceding units. The program was the sixth revision of a so-called Math Drill and Practice Program, developped 1964 at the Stanford Institute for Mathematical Studies in the Social Sciences. It exclusively offered tutored practice and did not include an introduction in mathematical notions and procedures. However, since the curriculum material was carefully arranged in a hierarchical order, based on rational and empirical analysis, and since the increase in difficulty was gradual, the distinction between introduction and practice became less pertinent. Nevertheless poor instruction managment by the classroom teacher might have encouraged some brighter students to go ahead with curriculum units they had not been prepared for. This effect would not have crucially affected trends of increasing or decreasing correlations or variances over time.

The complete mathematics curriculum for elementary instruction contained the customary coverage for grades 1 through 7. It was structured by a horizontal classification into 14 strands including each all problem types of a given broad concept (e.g., vertical subtraction, fractions). Some strands covered all seven grades, some strands ran only through several grades (e.g., number concept from 1 to 7, horizontal multiplication from 2 to 5). Within each strand, problems of an even more homogeneous type were vertically grouped into equivalent classes (ec's) (e.g., "horizontal" additions with sums between 0 and 5). Per strand and grade there were either 10 or 20 (or 0) ec's. The students worked simultaneously on problems stemming from all of the strands which pertained to the grade the students were in. After each problem a random number generator observing predetdermined frequency distributions decided out of which strand the next problem was to be allocated. The average grade, determined by the individual ec level within each strand, indicated the apropriate set of electable strands.

The students were working on on-line terminals: input and output were exclusively through typewriters. The problems in each strand were preformulated and stored, ordered in a fix sequence. The progress rule for the learner was as follows:

If he correctly solves problem i:

but not his preceding one	his next problem is i+1
and if problem i is the second of a series of correctly solved problems	his next problem is i+2
and at least his two immediately preceding ones	his next problem is i+3

If he fails to solve problem i:

but not his preceding one	his next problem is i-1
and has also failed his preceding one but not the one before	his next problem is i-2
and he has an immediately preceding series of exactly 2 failures	his next problem is i-3
and he has an immediately preceding series of exactly 3 failures	his next problem is i-4
and he has an immediately preceding series of at least 4 failures	his next problem is i-5

The problem series were linearly sequenced. The progress rule applied for each strand separately. After random allocation to a specific strand, the computer acted on the students history of this strand. If a student did not answer within twenty seconds, he was invited again to answer, and after another twenty seconds the correct answer was typed out, and the student was asked to copy it. The progress rule would handle this as a failure. Incorrect answers were immediately classified and subsequently presented again. If a third presentation was necessary, the correct answer was printed out, and the student was asked to copy it. Each student was usually allowed to work every day as many minutes as he was years old. For a more detailed description of the program see Suppes et al. (1971) and Friend (1971).

Subjects

The subjects were 723 normal elementary school students of grades 1 through 6. The students worked at the terminals of their schools in California, Arizona and Texas, connected by telephone to Stanford University. About two thirds of the students were unfamiliar with the program. This effect was controlled by not considering the first month.

Procedure

In order to keep the large data body and processing time within reasonable limits, six strands were selected for this study:

1) strand 2	horizontal addition	grades 1 through 3
2) strand 3	horizontal subtraction	grades 1 through 3
3) strand 4	vertical addition	grades 1 through 5
4) strand 5	vertical subtraction	grades 1 through 5
5) strand 11	subtraction	grades 3 through 5
6) strand 12	fractions	grades 3 through 5

The learning time X_{ijk} was defined as the time that the ith subject spent while working on problems of the jth strand, measured from the beginning of the first problem's presentation belonging to the kth ec (ec_{jk}) through the beginning of the presentation of the first $ec_{j,k+1}$ problem. In this way the time it took the computer to print out and the time it took the subject to type his answer was also recorded as learning time, because it was felt that information processing beneficial to learning was continuing during these activities. Since the progress rule was not affected in any way by ec limits, the first problem that the ith subject received out of ec_{jk} was not necessarily the first one in the objective problem series of that ec. Moreover, when poor performance in ec_{jk} led the student back to $ec_{j,k-1}$, the time was counted for x_{ijk} since difficulties within ec_{jk} caused the setback.

Several times during the year, certain breakdowns of the system caused the daily history of those subjects who were just working on their lessons to be lost. Subjects with missing data were excluded from the analysis of the corresponding curriculum part. The sample per processing unit included those students who during half a year went through the complete curriculum of the respective strand and did not show any data losses. A half-year period constituted a processing unit. Some minor data losses were no longer detectable with the prepared program package. But this should not have affected the results in any systematic way.

RESULTS

The results indicate that there were no differences between the six strands. Thus, in order to increase the degrees of freedom and to decrease the number of tables, the results have been averaged for each curriculum grade over all strands and the two half-years (except for the very first, standing for the school beginners), each weighed for the corresponding number of degrees of freedom.

The first hypothesis was that the variability of the learning times was positively related to the amount of preceding Non-Mastery Learning Strategy instruction, i.e., that Non-MLS increased variability as predicted by Bloom. The higher the grades, the longer the Ss had previously had Non-MLS instruction. Variability coefficients have been calculated as 'Standard Deviation/Arithmetic Mean' quotients.

Table 1

Average variability coefficients per grade

Grade	Variability coefficient
1, first half-year	.819
1, second half-year	.940
1, combined	.926
2	1.021
3	.905
4	1.350
5	1.061

In Table 1 all the variability coefficients are averaged over strands and equivalent classes. The significance test of a linear trend was based on all 210 variability coefficients. This hypothesis was not confirmed. ($r = .106$; $df = 208$; $p > .10$; two-tailed).

The second hypothesis stated that ID's would decrease under continued Mastery-Learning Strategy. This hypothesis, too, was not confirmed. In Table 2 changes of the variability coefficients over subsequent equivalent classes are presented for each grade. Except in the case of 10 equivalent classes in grade 4, all linear trends were not significant ($p > .05$, two-tailed); the exception can easily be attributed to the alpha error.

Table 2

Linear trends of the variability coefficients over subsequent equivalence classes (product-moment correlations as trend measures)

Grade	cases with 10 ec's per half-year			cases with 5 ec's per half-year		
	r	df	p(two-tailed)	r	df	p(two-tailed)
1, first half-year	+.19	8	>.05	+.12	8	>.05
1, second half-year	-.23	8	>.05	-.37	13	>.05
1, combined	-.07	18	>.05	-.01	23	>.05
2	-.14	38	>.05	+.02	18	>.05
3	-.14	28	>.05	-.36	23	>.05
4	-.35	28	<.05	-.10	18	>.05
5	+.01	28	>.05	-.23	13	>.05

The frequency distribution of the learning times were strongly positively skewed. This had to be expected, especially since the program was extremely 'patient' with students answering wrong or not at all. Therefore, before correlations were calculated, the learning time scales were transformed by normalizing the frequency distribution for every single ec_{jk}. Table 3 contains the averaged correlation coefficients (averaged while being transformed into Fisher's z and weighed for degrees of freedom). While

this table shows the correlations as calculated for the original learning times together with those calculated for the transformed scale, all further correlations are based on the transformed scale.

Table 3
Average correlation coefficients per grade

Grade	Correlations calculated on the		df
	Original learning times	Transformed scale	
1, first half-year	.66	.27	1865
1, second half-year	.58	.20	7635
1, combined	.59	.21	9000
2	.52	.25	25940
3	.54	.28	18410
4	.43	.28	16740
5	.56	.24	5810

The third hypothesis assumed that school beginners had not been previously exposed to Non-Mastery-Learning Strategy instruction. Therefore supposedly they should not show any correlation between learning times for the mastery of succeeding learning units. This null hypothesis was rejected (average correlation =.27; df = 1365; $p \ll .01$).

The fourth hypothesis was parallel to the first one. It was expected that the inter equivalent class correlation would increase with the amount of preceding Non-Mastery Learning Strategy instruction. Table 4 contains the coefficients of the linear trend over the grades, separate for each correlation matrix diagonal. The hypothesis had to be rejected ($p > .05$, except for one case out of 13).

Table 4

Linear trends of the intercorrelations over the grades (product moment correlations as trend indices)

Diagonal	cases with 10 ec's per half-year r	df	p (two-tailed)	cases with 5 ec's per half year r	df	p (two-tailed)
2	.02	142	>.05	-.16	82	>.05
3	.17	126	>.05	-.04	61	>.05
4	-.11	110	>.05	.13	40	>.05
5	.21	94	<.05	.20	19	>.05
6	-.10	78	>.05			
7	-.01	62	>.05			
8	.08	46	>.05			
9	.12	30	>.05			
10	.37	14	>.05			

The fifth hypothesis paralleled the second one, stating that the learning time correlations of adjacent ec's would successively decrease, i.e., that continuous MLS would reduce ID variance as well as covariance. As table 5 shows, only in grade 5, there was a significant, negative linear trend. Many trends are even positive, however they are not significant.

Table 5

Linear trends of the correlations between successively adjacent ec's (product moment correlations as trend indices)

	case with 10 ec's per half-year			case with 5 ec's per half-year		
	r	df	p(two-tailed)	r	df	p(two-tailed)
1, first half	-.49	7	>.05	-.34	6	>.05
1, second half	-.24	7	>.05	.03	10	>.05
1, combined	-.36	16	>.05	-.17	18	>.05
2	.18	34	>.05	.36	14	>.05
3	.15	25	>.05	-.02	22	>.05
4	.16	34	>.05	.30	14	>.05
5	-.42	25	<.05	-.13	10	>.05

DISCUSSION

Corresponding to Bloom's prediction that the Mastery-Learning Strategy would decrease ID's, the development of the variance and the covariance of needed learning times per mastery unit was tested. Neither variance decrease nor correlation decrease showed up by far. The absolute values of the correlation were appreciable and the pooling of such a vast body of data raised the degrees of freedom in such a way that significant trends should have become apparent over periods as long as half a curriculum year. Under the conditions of the present experiment the theoretical basis of Bloom's (1971) hypothesis of decreasing individual differences under a Mastery-Learning Strategy does not appear to be sound.

These findings also invalidate the strong Overlap Hypothesis and the interpretation of the simplex in learning data as an effect of "random walk". At least there is not exclusively random walk. This leads to the questions whether there is at all. The ec time correlation matrices have been calculated to see, whether these matrices, too, show the pattern of

decreasing correlation coefficients as they move from the diagonal to the upper-right corner. Table 6 shows that this is the case.

Table 6

Linear trends of the correlations over the distance from the main diagonal (product moment correlations as trend indices)

Grade	cases with 10 ec's per half-year			cases with 5 ec's per half-year		
	r	df	p(one-tailed)	r	df	p(one-tailed)
1, first half-year	-.36	43	<.05	-.46	18	<.05
1, second half-year	-.11	43	>.05	-.32	28	<.05
1, combined	-.27	88	<.05	-.36	48	<.05
2	-.19	178	<.05	-.29	38	<.05
3	-.13	133	<.05	-.09	48	>.05
4	-.17	178	<.05	-.15	38	>.05
5	.05	133		.21	28	

It would have been suprising, indeed, if such an effect would not have shown up. The simple assumption that the learning history of an individual is idiosyncratically changed, so that as least a fraction of his change is unpredictable but has a minimal further endurance or overlap suffices to explain the decrease of the correlations. Thus the data support a restricted overlap model. But again, the mere simplex-like correlation decrease does not tell whether all the change is unrelated nor how much of it is.

With regard to the lack of any trend towards a "vanishing point" of individual differences, as Bloom predicted, two more points need to be stressed. First, Bloom is probably right, when he assumes that below-average students might inreasingly fall behind with respect to the average (relatively spoken) when the teacher adopts a strategy like "The class goes on, if three quarters of the students mastered the preceding unit". But it seems likewise reasonable to assume that bright students under the same

instruction are also impeded, because they have to wait, until most of the other students are ready. In this case Computer-Assisted Instruction with a progress rule as the one described in this paper would both allow the faster learner to go on faster and provide the slower learner with the necessary skills in order to make him learn more per unit. These two effects could have compensated one another in terms of variance and covariance.

However, if a Mastery-Learning Strategy is realized by ordinary class instruction complemented by remedial teaching - a procedure Bloom and his students apparently adopted for their investigations (see also Block, 1971) - the first mechanism, only, should be expected to have operated, i.e., a closer approximation of the slower students to the average performance level. Since the faster students apparently were not encouraged to carry on, the compensatory increase in ID variance did not emerge. On the basis of this argument, Bloom's communication with respect to some trends towards a vanishing point would not be inconsistent with the results reported here.

A second point is that neither Bloom nor any other Mastery-Learning Strategy advocate asserts that one type of instruction, for example Computer-Assisted Instruction, alone inevitably reduces individual differences under MLS. Bloom explicitly pointed out, that the teacher should always try to find the best remedial instruction for every individual. It might well be argued that for some students Computer-Assisted Instruction did not represent their personal best learning method, while for other students it was an optimal instruction tool. Interactions of this sort are due to several variables, namely cognitive and emotional factors. The present investigation has not disproven this narrow interpretation's assumption.

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